REPORT DOCUMENTATION PAGE

AFOSR-TR-97

0582

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE 11/4/97

3. REPORT

4. TITLE AND SUBTITLE

FINAL REPORT: TOPICS IN UNCONVENTIONAL IMAGERY

5. FUNDING NUMBERS

F49620-96-1-0352

6. AUTHOR(S)

B. Roy Frieden, principal investigator
David J. Graser, doctoral graduate student

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Optical Sciences Center
University of Arizona
P. O. Box 210094
Tucson, Arizona 85721

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Office of Scientific Research/NE
110 Duncan Avenue, Room B115
Bolling Air Force Base
Washington, D.C. 20332-8080

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unlimited

12b. DISTRIBUTION CODE

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

13. ABSTRACT (Maximum 200 words)

Two problems in unconventional imagery were worked on, (a) an exact solution to the image turbulence problem (also called the 'blind deconvolution' problem); and (b) closed-form maximum entropy (M.E.) image restoration. Progress on (a) was as follows. It was found that by dividing the image spectra of two short-exposure images of an incoherent object viewed through random turbulence, a system of linear equations can be generated. The unknowns of the equations are the sampled values of the two point spread functions characterizing the two images. These can be found, with arbitrary precision, by simple inversion of the equations. Then the object is restored by inverse filtering the two images with transfer functions generated from the known point spread functions. The approach works perfectly in the absence of additional randomness due to noise of detection, and tolerates small amounts of such noise. Progress on (b) was as follows. Doctoral student David Graser tested out the closed-form M.E. approach by computer simulation. Two widely-used classes of test objects--point sources and edge sources--were used as inputs, and these were imaged using Gaussian spread functions of given halfwidths. The M.E. outputs were found to be, overall, superior to corresponding outputs using clipped inverse-filtering and Wiener filtering.

14. SUBJECT TERMS

image reconstruction; clear air turbulence; wind shear detection

15. NUMBER OF PAGES 3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

FINAL REPORT, Grant # F49620-96-1-0352

TOPICS IN UNCONVENTIONAL IMAGERY

B. Roy Frieden
tel: (520) 621-4904
fax: (520) 621-6778
email: friedenr@super.arizona.edu

SCIENTIFIC PERSONNEL

B. R. Frieden, principal investigator
David J. Graser, doctoral graduate student

PROBLEMS UNDER STUDY:

Adequate lead time against incoming missiles is of critical importance to limited-area defense. Lead time can be maximized if the missiles can be recognized when they are very far off, i.e., when their images are very small. Such images are degraded, however, by the effects of random atmospheric turbulence.

Digital image processing allows completely flexible processing of such images. Given the lead-time problem, the aim is to develop fast and effective methods of restoring missile images. The speed requirement also necessitates that the restoring method be based upon a minimal number of images to be used as input data.

Atmospheric wind shear has been the cause of many air crashes. Present methods of detecting wind shear require expensive, delicate, active optical probes such as lidar. It would be better to find an inexpensive, robust, passive method of detecting the problem. The 'image division' algorithm (approach (a) below) is a passive method, and should be applicable to the wind-shear turbulence identification problem (see below).

SUMMARY OF ACCOMPLISHMENTS

Two different approaches to image restoration were investigated: (a) the 'image division' method, and (b) closed-form maximum entropy (M.E.) restoration.

The approach (a) may be briefly described as follows (for details, see the paper "Exact, linear solution to the image turbulence problem"; this may be obtained by request from this author or, when it is published, by consulting the appropriate journal). An incoherent object is imaged twice in succession using short exposures, i.e., the order of 1/60 s of shorter. The Fourier transform of each image is taken, and then their quotient is formed. By the transfer theorem, numerator and denominator contain a common factor in the object spectrum. This cancels, leaving a

quotient of Fourier series where, by the sampling theorem, the coefficients of the series are the two point spread functions characterizing the images. By evaluating this quotient equation at a series of frequencies, a series of *linear equations* in the unknown point spread function values may be generated. This system of equations can be inverted to yield the unknown point spread function values. Once these are known, their Fourier transforms yield two optical transfer functions. Each may be applied to its corresponding image to effect inverse filtering. The two outputs are two versions of the input object. These may be averaged to produce one overall output.

It is to be noted that but two images are needed as inputs, which aids the speed requirement. Also, no reference point sources are required. The division operation is the key step of the approach, eliminating as it does the object unknowns from the problem, while defining a set of linear equations for the other unknowns of the problem - the two point spread functions.

Approach (b) may be briefly described as follows (for details, see the paper "Closed-form maximum entropy image restoration", to be published in Optics Communications). A maximum entropy restoration may be expressed in the general form of *the exponential* of the convolution of a kernel function with the given image data. The kernel function specifies the particular object, and must be found. By the use of a log-L_2 error norm, the kernel function, denoted as $\lambda(x)$, is found to be the Fourier transform of a function $\Lambda(\omega) = \frac{\langle I^*(\omega)L(\omega)\rangle}{\phi_I(\omega)}$, where $L(\omega)$ is the Fourier transform of the logarithm of the object, and $\phi_I(\omega)$ is the power spectrum of the class of images. Brackets < > denote an ensemble average. The output restoration obeys positivity, by the exponential form it takes. This permits significant bandwidth extrapolation and, hence, super resolution, to be attained. At the same time, the approach does not require the iterative search procedure that is characteristic of other maximum entropy approaches. Such search procedures are very wasteful of time.

Both approaches (a) and (b) have been largely successful, as described below.

The detection of wind shear conditions should be accomplishable by the use of approach (a) of image division. The presence of wind shear should manifest itself as point spread functions of a characteristic shape (perhaps stretched out in the direction of the wind). Since the image division method restores the point spread functions for given turbulence conditions, this should identify conditions of wind shear.

FURTHER DEVELOPMENT WORK

(a) The image division method works well (virtually perfectly) in the presence of random atmospheric turbulence. However, it becomes unstable in the presence of additional noise of detection. Currently, it can tolerate up to 1% additive noise of detection. The approach can probably be modified to accomplish a degree of regularization, such that noise sensitivity is decreased. This would be at the expense of some resolution, as is inevitable with regularization approaches. The aim would be to produce an algorithm that tolerates (say) 10% additive noise of detection with minimal sacrifice of resolution.

(b) Closed-form maximum entropy is effective but, presently, requires extensive prior knowledge of object class and noise class. A more practical algorithm would not presume such knowledge, and we will work toward developing such an algorithm in future research.

PUBLICATIONS

B.R. Frieden and D.J. Graser, "Closed-form maximum entropy image restoration", Optics Communications (to be published)

B.R. Frieden, "Exact, linear solution to the image turbulence problem", Optics Communications (under review)

ORAL PAPER

B.R. Frieden and D.J. Graser, "Closed-form maximum entropy image restoration", SPIE Annual Conv., San Diego (1997)